

StarPU Handbook - StarPU Applications

for StarPU 1.4.5

	1
1 Organization	3
2 A Vector Scaling Application	5
2.1 Base version	5
2.2 StarPU C version	5
2.2.1 Computation Kernels	5
2.2.2 Main Code	6
2.3 Building and Running	7
3 A Stencil Application	9
3.1 The Original Application	9
3.2 The StarPU Application	9
3.3 The StarPU MPI Application	11
3.4 Running the application	12
I Appendix	13
4 The GNU Free Documentation License	15
4.1 ADDENDUM: How to use this License for your documents	19

This manual documents the usage of StarPU version 1.4.5. Its contents was last updated on 2024-04-19.

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Chapter 1

Organization

This part presents how to write a StarPU application from an existing application.
Some of the applications presented in the following chapters and some others are available in the git repository
<https://gitlab.inria.fr/starpu/starpu-applications>

Chapter 2

A Vector Scaling Application

2.1 Base version

The non-StarPU version shows a basic example that we will be using to illustrate how to use StarPU. It simply allocates a vector, and calls a scaling function over it.

```
void vector_scal_cpu(float *val, unsigned n, float factor)
{
    unsigned i;
    for (i = 0; i < n; i++)
        val[i] *= factor;
}
#define NX 2048
int main(void)
{
    float *vector;
    unsigned i;
    vector = malloc(sizeof(vector[0]) * NX);
    for (i = 0; i < NX; i++)
        vector[i] = 1.0f;
    fprintf(stderr, "BEFORE : First element was %f\n", vector[0]);
    float factor = 3.14;
    vector_scal_cpu(vector, NX, factor);
    fprintf(stderr, "AFTER First element is %f\n", vector[0]);
    free(vector);
    return 0;
}
```

2.2 StarPU C version

2.2.1 Computation Kernels

We are going to transform here the computation function `vector_scal_cpu`.

```
void vector_scal_cpu(float *val, unsigned n, float factor)
{
    unsigned i;
    for (i = 0; i < n; i++)
        val[i] *= factor;
}
```

The StarPU corresponding function takes as parameters a list of DSM interfaces and a non-DSM parameter.

```
void vector_scal_cpu(void *buffers[], void *cl_arg)
{
```

The first DSM parameter is the vector and is available through `buffer[0]`. StarPU provides functions to get the vector data, and extract the pointer and size of the vector.

```
    struct starpu_vector_interface *vector = buffers[0];
    float *val = (float *)STARPU_VECTOR_GET_PTR(vector);
    unsigned n = STARPU_VECTOR_GET_NX(vector);
```

The non-DSM parameters are stored in the second argument of the function, and need to be unpacked.

```
    float factor;
    starpu_codelet_unpack_args(cl_arg, &factor);
```

It is then possible to perform the vector scaling as in the original function.

```
    unsigned i;
    for (i = 0; i < n; i++)
        val[i] *= factor;
```

Original code	StarPU code
<pre>void vector_scal_cpu(float *val, unsigned n, float factor) { unsigned i; for (i = 0; i < n; i++) val[i] *= factor; }</pre>	<pre>void vector_scal_cpu(void *buffers[], void *cl_arg) { struct starpu_vector_interface *vector = buffers[0]; float *val = (float *)STARPU_VECTOR_GET_PTR(vector); unsigned n = STARPU_VECTOR_GET_NX(vector); float factor; starpu_codelet_unpack_args(cl_arg, &factor); unsigned i; for (i = 0; i < n; i++) val[i] *= factor; }</pre>

The GPU and OpenCL implementations can be seen in `FullSourceCodeVectorScal`.

2.2.2 Main Code

Let's look now at the main code.

- The `cl` codelet structure simply gathers pointers on the functions mentioned above, and notes that the functions takes only one DSM parameter.

```
static struct starpu_codelet cl =
{
    .cpu_funcs = {vector_scal_cpu},
    .cuda_funcs = {vector_scal_cuda},
    .opencl_funcs = {vector_scal_opencl},
    .nbuffers = 1,
    .modes = {STARPU_RW}
};
```

- The `main` function starts with initializing StarPU with the default parameters.

```
int ret = starpu_init(NULL);
STARPU_CHECK_RETURN_VALUE(ret, "starpu_init");
```

- It then allocates the vector and fills it like the original code.

```
vector = malloc(sizeof(vector[0]) * NX);
for (i = 0; i < NX; i++)
    vector[i] = 1.0f;
fprintf(stderr, "BEFORE : First element was %f\n", vector[0]);
```

- It then registers the data to StarPU, and gets back a DSM handle. From now on, the application is not supposed to access `vector` directly, since its content may be copied and modified by a task on a GPU, the main-memory copy then being outdated.

```
starpu_data_handle_t vector_handle;
starpu_vector_data_register(&vector_handle, STARPU_MAIN_RAM, (uintptr_t)vector, NX,
sizeof(vector[0]));
```

- It then submits a (asynchronous) task to StarPU.

```
float factor = 3.14;
ret = starpu_task_insert(&cl,
    STARPU_RW, vector_handle,
    STARPU_VALUE, &factor, sizeof(factor),
    0);
STARPU_CHECK_RETURN_VALUE(ret, "starpu_task_insert");
```

- It waits for task completion, and unregisters the vector from StarPU, which brings back the modified version to main memory, so the result can be read.

```
starpu_task_wait_for_all();
starpu_data_unregister(vector_handle);
```

- Eventually, it shuts down StarPU:

```
starpu_shutdown();
```

Original code	StarPU code
<pre> #define NX 2048 int main(void) { float *vector; unsigned i; vector = malloc(sizeof(vector[0]) * NX); for (i = 0; i < NX; i++) vector[i] = 1.0f; fprintf(stderr, "BEFORE : First element was %f\n", vector[0]); float factor = 3.14; vector_scal_cpu(vector, NX, factor); fprintf(stderr, "AFTER First element is %f\n", vector[0]); free(vector); return 0; } </pre>	<pre> #include <starpu.h> extern void vector_scal_cpu(void *buffers[], void *_args); extern void vector_scal_cuda(void *buffers[], void *_args); extern void vector_scal_opencl(void *buffers[], void *_args); static struct starpu_codelet cl = { .cpu_funcs = {vector_scal_cpu}, .cuda_funcs = {vector_scal_cuda}, .opencl_funcs = {vector_scal_opencl}, .nbuffers = 1, .modes = {STARPU_RW} }; #ifdef STARPU_USE_OPENCL struct starpu_opencl_program programs; #endif #define NX 2048 int main(void) { float *vector; unsigned i; int ret = starpu_init(NULL); STARPU_CHECK_RETURN_VALUE(ret, "starpu_init"); #ifdef STARPU_USE_OPENCL starpu_opencl_load_opencl_from_file("vector_scal_opencl_kernel.cl", &programs, NULL); #endif vector = malloc(sizeof(vector[0]) * NX); for (i = 0; i < NX; i++) vector[i] = 1.0f; fprintf(stderr, "BEFORE : First element was %f\n", vector[0]); starpu_data_handle_t vector_handle; starpu_vector_data_register(&vector_handle, STARPU_MAIN_RAM, (uintptr_t)vector, NX, sizeof(vector[0])); float factor = 3.14; ret = starpu_task_insert(&cl, STARPU_RW, vector_handle, STARPU_VALUE, &factor, sizeof(factor), 0); STARPU_CHECK_RETURN_VALUE(ret, "starpu_task_insert"); starpu_task_wait_for_all(); starpu_data_unregister(vector_handle); fprintf(stderr, "AFTER First element is %f\n", vector[0]); free(vector); #ifdef STARPU_USE_OPENCL starpu_opencl_unload_opencl(&programs); #endif starpu_shutdown(); return 0; } </pre>

2.3 Building and Running

We will use the StarPU docker image.

```
$ docker run -it registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

If your machine has GPU devices, you can use the following command to enable the GPU devices within the docker image.

```
$ docker run -it --gpus all registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

From your docker image, you can then call the following commands.

```
$ cd src/starpu/doc/tutorial
$ make vector_scal
$ ./vector_scal
```

You can set the environment variable `STARPU_WORKER_STATS` to 1 when running your application to see the number of tasks executed by each device.

```
$ STARPU_WORKER_STATS=1 ./vector_scal
```

If your machine has GPU devices, you can force the execution on the GPU devices by setting the number of CPU workers to 0.

```
# to force the implementation on a GPU device, by default, it will enable CUDA  
$ STARPU_WORKER_STATS=1 STARPU_NCPU=0 ./vector_scal
```

```
# to force the implementation on a OpenCL device  
$ STARPU_WORKER_STATS=1 STARPU_NCPU=0 STARPU_NCUDA=0 ./vector_scal
```

Chapter 3

A Stencil Application

3.1 The Original Application

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(double *xy, double *xmly, double *xply, double *xym1, double *xyp1)
{
    *xy = (*xy + *xmly + *xply + *xym1 + *xyp1) / 5;
}
int main(int argc, char **argv)
{
    int niter, n;
    int x, y, loop;
    read_params(argc, argv, &n, &niter);
    double *A = calloc(n*n, sizeof(*A));
    fill(A, n, n);
    for(loop=0 ; loop<niter; loop++)
    {
        for (x = 0; x < n; x++)
        {
            for (y = 0; y < n; y++)
            {
                int xm1 = (x==0) ? n-1 : x-1;
                int xp1 = (x==n-1) ? 0 : x+1;
                int ym1 = (y==0) ? n-1 : y-1;
                int yp1 = (y==n-1) ? 0 : y+1;
                stencil5_cpu(&A[_(x,y,n)],
                            &A[_(xm1,y,n)], &A[_(xp1,y,n)],
                            &A[_(x,ym1,n)], &A[_(x,yp1,n)]);
            }
        }
    }
    return 0;
}
```

3.2 The StarPU Application

The computation function must be defined through a codelet.

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args)
{
    (void)_args;
    double *xy = (double *)STARPU_VARIABLE_GET_PTR(descr[0]);
    double *xmly = (double *)STARPU_VARIABLE_GET_PTR(descr[1]);
    double *xp1y = (double *)STARPU_VARIABLE_GET_PTR(descr[2]);
    double *xym1 = (double *)STARPU_VARIABLE_GET_PTR(descr[3]);
    double *xyp1 = (double *)STARPU_VARIABLE_GET_PTR(descr[4]);
    *xy = (*xy + *xmly + *xp1y + *xym1 + *xyp1) / 5;
}
struct starpu_codelet stencil5_cl =
{
    .cpu_funcs = {stencil5_cpu},
    .nbuffers = 5,
    .modes = {STARPU_RW, STARPU_R, STARPU_R, STARPU_R, STARPU_R},
    .model = &starpu_perfmodel_nop,
};
```

Data must be registered to StarPU.

```
data_handles = malloc(n*n*sizeof(*data_handles));
for(x = 0; x < n; x++)
{
    for (y = 0; y < n; y++)
    {
```

```

        starpu_variable_data_register(&data_handles[_(x,y,n)],
                                     STARPU_MAIN_RAM,
                                     (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
    }
}

```

Instead of directly calling the function, a StarPU task must be created.

```

int xml = (x==0) ? n-1 : x-1;
int xpl = (x==n-1) ? 0 : x+1;
int yml = (y==0) ? n-1 : y-1;
int ypl = (y==n-1) ? 0 : y+1;
starpu_task_insert(&stencil5_cl,
                  STARPU_RW, data_handles[_(x,y,n)],
                  STARPU_R, data_handles[_(xml,y,n)],
                  STARPU_R, data_handles[_(xpl,y,n)],
                  STARPU_R, data_handles[_(x,yml,n)],
                  STARPU_R, data_handles[_(x,ypl,n)],
                  0);

```

And finally data must be released from StarPU.

```

for(x = 0; x < n; x++)
{
    for(y = 0; y < n; y++)
    {
        starpu_data_unregister(data_handles[_(x,y,n)]);
    }
}

```

The whole StarPU application looks as follows.

```

#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args)
{
    (void)_args;
    double *xy = (double *)STARPU_VARIABLE_GET_PTR(descr[0]);
    double *xmly = (double *)STARPU_VARIABLE_GET_PTR(descr[1]);
    double *xply = (double *)STARPU_VARIABLE_GET_PTR(descr[2]);
    double *xym1 = (double *)STARPU_VARIABLE_GET_PTR(descr[3]);
    double *xypl = (double *)STARPU_VARIABLE_GET_PTR(descr[4]);
    *xy = (*xy + *xmly + *xply + *xym1 + *xypl) / 5;
}
struct starpu_codelet stencil5_cl =
{
    .cpu_funcs = {stencil5_cpu},
    .nbuffers = 5,
    .modes = {STARPU_RW, STARPU_R, STARPU_R, STARPU_R, STARPU_R},
    .model = &starpu_perfmodel_nop,
};
int main(int argc, char **argv)
{
    starpu_data_handle_t *data_handles;
    int ret;
    int niter, n;
    int x, y, loop;
    ret = starpu_init(NULL);
    STARPU_CHECK_RETURN_VALUE(ret, "starpu_init");
    read_params(argc, argv, &verbose, &n, &niter);
    double *A = calloc(n*n, sizeof(*A));
    fill(A, n, n);
    data_handles = malloc(n*n*sizeof(*data_handles));
    for(x = 0; x < n; x++)
    {
        for(y = 0; y < n; y++)
        {
            starpu_variable_data_register(&data_handles[_(x,y,n)],
                                         STARPU_MAIN_RAM,
                                         (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
        }
    }
    for(loop=0 ; loop<niter; loop++)
    {
        for(x = 0; x < n; x++)
        {
            for(y = 0; y < n; y++)
            {
                int xml = (x==0) ? n-1 : x-1;
                int xpl = (x==n-1) ? 0 : x+1;
                int yml = (y==0) ? n-1 : y-1;
                int ypl = (y==n-1) ? 0 : y+1;
                starpu_task_insert(&stencil5_cl,
                                STARPU_RW, data_handles[_(x,y,n)],
                                STARPU_R, data_handles[_(xml,y,n)],
                                STARPU_R, data_handles[_(xpl,y,n)],
                                STARPU_R, data_handles[_(x,yml,n)],
                                STARPU_R, data_handles[_(x,ypl,n)],
                                0);
            }
        }
    }
    starpu_task_wait_for_all();
}

```

```

for(x = 0; x < n; x++)
{
    for (y = 0; y < n; y++)
    {
        starpu_data_unregister(data_handles[_(x,y,n)]);
    }
}
starpu_shutdown();
return 0;
}

```

3.3 The StarPU MPI Application

The initialisation for StarPU-MPI is as follows.

```

int ret = starpu_mpi_init_conf(&argc, &argv, 1, MPI_COMM_WORLD, NULL);
STARPU_CHECK_RETURN_VALUE(ret, "starpu_mpi_init_conf");
starpu_mpi_comm_rank(MPI_COMM_WORLD, &my_rank);
starpu_mpi_comm_size(MPI_COMM_WORLD, &size);

```

An additional call to `starpu_mpi_data_register()` is necessary.

```

starpu_variable_data_register(&data_handles[_(x,y,n)],
                             STARPU_MAIN_RAM,
                             (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
int mpi_rank = my_distrib(x, y, size);
starpu_mpi_data_register(data_handles[_(x,y,n)], (y*n)+x, mpi_rank);

```

And to insert a task, the function `starpu_mpi_task_insert()` must be used.

```

starpu_mpi_task_insert(MPI_COMM_WORLD, &stencil5_cl,
                      STARPU_RW, data_handles[_(x,y,n)],
                      STARPU_R, data_handles[_(xm1,y,n)],
                      STARPU_R, data_handles[_(xpl,y,n)],
                      STARPU_R, data_handles[_(x,ym1,n)],
                      STARPU_R, data_handles[_(x,ypl,n)],
                      0);

```

The whole StarPU-MPI application looks as follows.

```

#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args); // Same as in sequential StarPU
struct starpu_codelet stencil5_cl; // Same as in sequential StarPU
/* Returns the MPI node number where data indexes index is */
int my_distrib(int x, int y, int nb_nodes)
{
    return ((int)(x / sqrt(nb_nodes) + (y / sqrt(nb_nodes)) * sqrt(nb_nodes))) % nb_nodes;
}
int main(int argc, char **argv)
{
    starpu_data_handle_t *data_handles;
    int niter, n;
    int my_rank, size, x, y, loop;
    int ret = starpu_mpi_init_conf(&argc, &argv, 1, MPI_COMM_WORLD, NULL);
    STARPU_CHECK_RETURN_VALUE(ret, "starpu_mpi_init_conf");
    starpu_mpi_comm_rank(MPI_COMM_WORLD, &my_rank);
    starpu_mpi_comm_size(MPI_COMM_WORLD, &size);
    read_params(argc, argv, &n, &niter);
    double *A = calloc(n*n, sizeof(*A));
    fill(A, n, n);
    data_handles = malloc(n*n*sizeof(*data_handles));
    for(x = 0; x < n; x++)
    {
        for (y = 0; y < n; y++)
        {
            starpu_variable_data_register(&data_handles[_(x,y,n)],
                                         STARPU_MAIN_RAM,
                                         (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
            int mpi_rank = my_distrib(x, y, size);
            starpu_mpi_data_register(data_handles[_(x,y,n)], (y*n)+x, mpi_rank);
        }
    }
    for(loop=0 ; loop<niter; loop++)
    {
        for (x = 0; x < n; x++)
        {
            for (y = 0; y < n; y++)
            {
                int xm1 = (x==0) ? n-1 : x-1;
                int xpl = (x==n-1) ? 0 : x+1;
                int ym1 = (y==0) ? n-1 : y-1;
                int ypl = (y==n-1) ? 0 : y+1;
                starpu_mpi_task_insert(MPI_COMM_WORLD, &stencil5_cl,
                                      STARPU_RW, data_handles[_(x,y,n)],
                                      STARPU_R, data_handles[_(xm1,y,n)],
                                      STARPU_R, data_handles[_(xpl,y,n)],
                                      STARPU_R, data_handles[_(x,ym1,n)],
                                      STARPU_R, data_handles[_(x,ypl,n)],
                                      0);
            }
        }
    }
}

```

```
    }  
  }  
  starpu_task_wait_for_all();  
  /* bring data back to node 0 and unregister it */  
  for(x = 0; x < n; x++)  
  {  
    for (y = 0; y < n; y++)  
    {  
      starpu_mpi_data_migrate(MPI_COMM_WORLD, data_handles[_(x,y,n)], 0);  
      starpu_data_unregister(data_handles[_(x,y,n)]);  
    }  
  }  
  starpu_mpi_shutdown();  
  return 0;  
}
```

3.4 Running the application

```
$ docker run -it registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

If your machine has GPU devices, you can use the following command to enable the GPU devices within the docker image.

```
$ docker run -it --gpus all registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

From your docker image, you can then call the following commands.

```
$ git clone https://gitlab.inria.fr/starpu/starpu-applications.git  
$ cd starpu-applications/stencil5  
$ make
```

To run the non-StarPU application

```
$ ./stencil5 -v
```

To run the sequential StarPU application

```
$ ./stencil5_starpu -v
```

To run the StarPU MPI application. Setting the variable STARPU_COMM_STATS to 1 will display the amount of communication between the different MPI processes.

```
$ STARPU_COMM_STATS=1 mpirun -np 4 ./stencil5_starpu_mpi -v 4 3
```

Part I

Appendix

Chapter 4

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